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Fuzzy logic-based controller design for brushless DC motor drives

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ABSTRACT

The paper presents a fuzzy logic controller for brushless direct current (BLDC) motor drives. Initially a fuzzy logic controller is developed using MATLAB Fuzzy-Logic Toolbox and then inserted into the Simulink model. The dynamic characteristics of the brushless DC motor such as speed, torque and current of the inverter components are observed and analyzed using the developed MATLAB model. The simulation and experimental results show that the brushless direct current motor (BLDC) is successfully and efficiently controlled by the Fuzzy logic controller.

Keywords - Fuzzy logic controller, Speed Control, BLDC motor drives.

1. INTRODUCTION

The development of high performance motor drives is very important in industrial as well as other applications such as steel rolling mills, electric trains and robotics. Generally, a high performance motor drive system must have good dynamic speed command tracking and load regulating response to perform task. DC drives, because of their simplicity, ease of application, high reliabilities, flexibilities and favorable cost have long been a backbone of industrial applications, robot manipulators and home appliances where speed and position control of motor are required.

The major problems in applying a conventional control algorithm in a speed controller are the effects of non-linearity in a DC motor. The nonlinear characteristics of a DC motor such as saturation and fiction could degrade the performance of conventional

controllers (M.Chow and A. Menozzi, 1992). Generally, an accurate nonlinear model of an actual DC motor is difficult to find and parameter obtained from systems identification may be only approximated values. Fuzzy control theory usually provides non-linear controllers that are capable of performing different complex non-linear control action, even for uncertain nonlinear Systems.

The model of motor drive has to be known in order to implement an effective control in simulation. Furthermore, fuzzy logic controllers (FLCs) have been used to analyze BLDC motor drives (Tan Chee Siong, Baharuddin, M.Fayzul and M.Faridun N.T, 2010). In this paper, a comprehensive simulation model with a fuzzy logic controller is presented. MATLAB/fuzzy logic toolbox is used to design the FLC, which is integrated into simulations with Simulink.

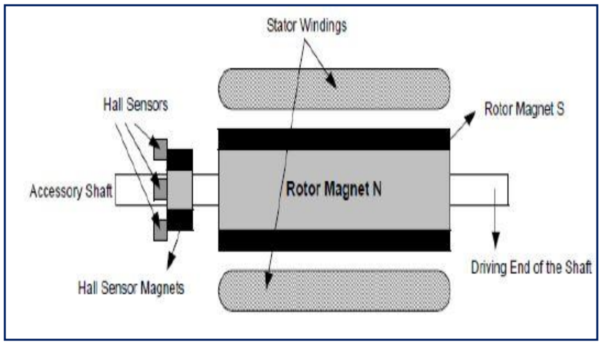

Figure 1

Transverse section structure of a brushless dc motor

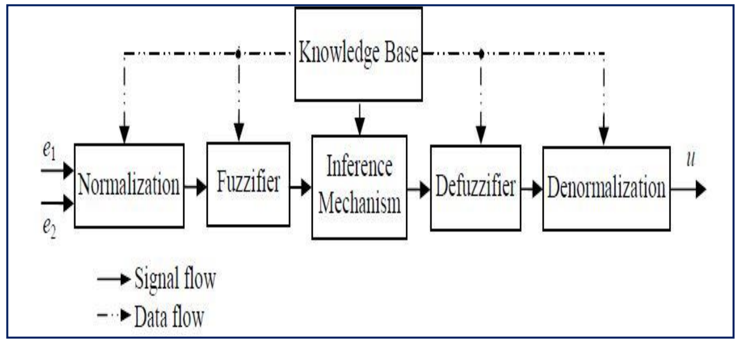

Figure 2

Structure of fuzzy logic controller

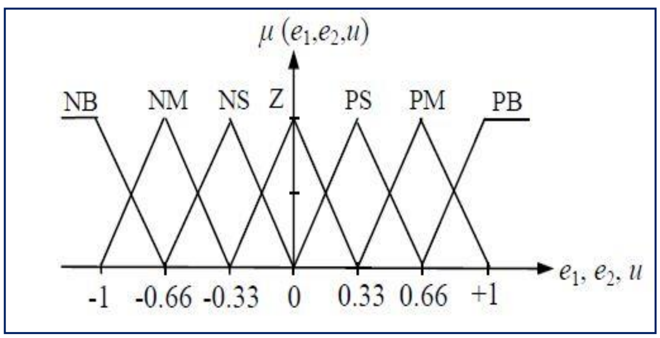

Figure 3

Membership functions of fuzzy controller

	Input-e_2						
Input-e_1	NB	NM	NS	Z	PS	PM	PB
NB	*PB*	*PB*	*PM*	*PM*	*PS*	*PS*	*Z*
NM	*PB*	*PM*	*PM*	*PS*	*PS*	*Z*	*NS*
NS	*PM*	*PM*	*PS*	*PS*	*Z*	*NS*	*NS*
Z	*PM*	*PS*	*PS*	*Z*	*NS*	*NS*	*NM*
PS	*PS*	*PS*	*Z*	*NS*	*NS*	*NM*	*NM*
PM	*PS*	*Z*	*NS*	*NS*	*NM*	*NM*	*NB*
PB	*Z*	*NS*	*NS*	*NM*	*NM*	*NB*	*NB*

Table 1

Rule base of fuzzy controller

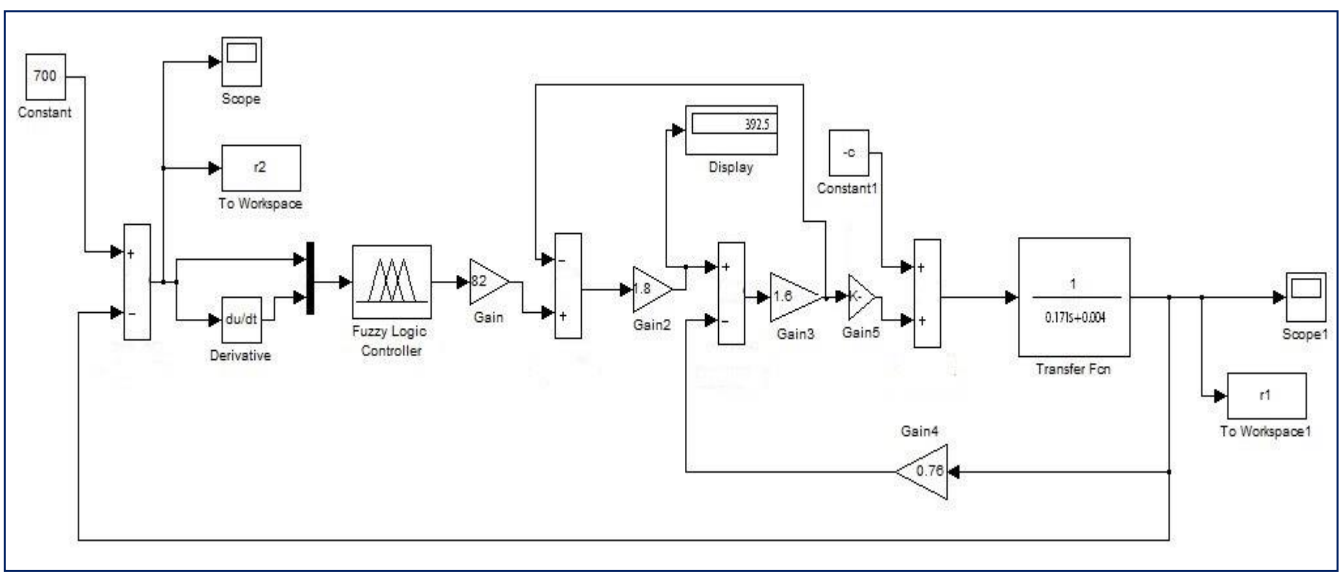

Figure 4

Matlab simulation diagram of fuzzy logic control

2. CONSTRUCTION AND OPERATING PRINCIPLE

BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic field generated by the rotor rotates at the same frequency. BLDC motors do not experience the “slip” that is normally seen in induction motors. BLDC motor is constructed with a permanent magnet rotor and wire wound stator poles. Brushless DC motors (BLDC) contain a powerful permanent magnet rotor and fixed stator windings. The stationary stator windings are usually three phases, which means that three separate voltages are supplied to the three different sets of windings. Figure 1 illustrates the transverse section structure of a brushless DC motor. Each commutation sequence (A W. Hong, W. Lee, and B.K. Lee, 2007) has one of the windings energized to positive power the second winding is negative and the third is in a non energized condition. Torque is produced because of the interaction between the magnetic field generated by the stator coils and the permanent magnets. Ideally, the peak torque occurs when these two fields are at 90° to each other and falls off as the fields move together. In order to keep the motor running, the magnetic field produced by the windings should shift position, as the rotor moves to catch up with the stator field (B. Sing, A.H.N. Reddy, and S.S. Murthy, 2003).

Armature resistance (Ra)	0.5 Ω
Armature inductance (La)	8 mH
Back e.m.f constant (K)	0.55 V/rad/s
Mechanical inertia (J)	0.0465 kg.m2
Friction coefficient (B)	0.004 N.m/rad/s
Rated armature current (Ia)	10 A

Table 2

The Parameter of DC Motor Drive System

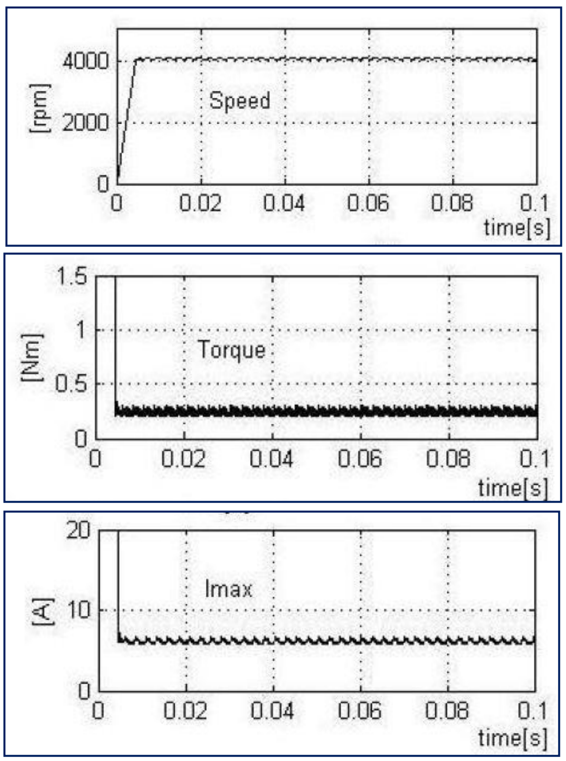

Figure 5

Electromagnetic torque, speed of BLDC motor, and maximum current (Imax)

3. DESIGN OF FUZZY LOGIC CONTROLLER (FLC)

The block diagram of FLC with two inputs (e1, e2) and one output (*u*) is shown in Figure 2. The error is calculated by subtracting the reference speed from the actual rotor speed as follows:

$$e1\,[n] = Wref\,[n] - Wr\,[n] \qquad (1)$$

Where *e1*[*n*] is the error, W*ref[n]* is the reference speed, and Wr[n] is the actual motor speed. The change in error is calculated by Equation (2), where *e1* [*n* −1] is the previous error value.

$$e2\,[n] = e1\,[n] - e1\,[n-1] \qquad (2)$$

In the fuzzy logic control system (Pavol Fedor and Daniela Perduková, 2005), two normalization parameters (N*e1*,N*e2*) for input and one denormalization parameter N(*u)* for output are defined. In normalization process, the input values are scaled between (-1, +1) and in the denormalization process, the output values of fuzzy controller are converted to a value depending on the terminal control element. The fuzzy values obtained from fuzzy inference mechanism have to be converted to crisp output value (*u*) by defuzzifier process. For this purpose, the triangle fuzzy membership function is defined for each input and output values by seven clusters. Figure 3 illustrates the membership function used to fuzzify two input values (*e*1, *e2*) and defuzziffy output (*u*) of the fuzzy controller. For seven clusters in the membership functions, seven linguistic variables are defined as: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB). A sliding mode rule base used in FLC is given in Table 1. The fuzzy inference operation is implemented by using the 49 rules (CK. Lee and WH. Pang, 1994). The min-max compositional rule of inference and the center-of-gravity method (Zadeh and L. A. et al., 1996) have been used in defuzzifier process.

If *e*1 is NB and *e*2 is NB Then *u* is PB,
If *e*1 is NB and *e*2 is NM Then *u* is PB,
If *e*1 is NB and *e*2 is NS Then *u* is PM,
If *e*1 is NB and *e*2 is Z Then *u* is PM,
………………………………………..
and go on for all inputs.

Simulation structure using fuzzy logic controller in Matlab

The Figure 4 shows the Matlab simulation diagram of the Fuzzy logic controller. The designed Matlab model has been used to observe the speed, torque and maximun current.

4. RESULTS

MATLAB Simulations

In order to validate the control strategies as described, digital simulations were carried out on a converter (K.B. Mohanty, 2004) for a DC motor drive system using MATLAB/SIMULINK, where the parameters used for the DC motor drive system is given in table 2. The digital simulation results are shown in the Figure 5. It shows the dynamic responses of the speed, torque and Imax, respectively. The reference value of maximum current (Imax) is computed from the generated constant torque reference, consequently it is used in the hysteresis control block.

5. CONCLUSION

The proposed fuzzy logic controller system has a good adaptability and strong robustness whenever the system is disturbed. The simulation model which is implemented in a modular manner under MATLAB environment allows dynamic characteristics such as phase currents, rotor speed, and mechanical torque to be effectively considered. Some of other adaptive enhancements technique such as artificial neural networks or neuro-fuzzy implementations could be used for future work.

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